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TECHNICAL INFORMATION BULLETIN 94-1

PROTECTION OF TELECOMMUNICATION LINKS FROM RADIATION EFFECTS

JANUARY 1994

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NCS TECHNICAL INFORMATION BULLETIN 94-1

PROTECTION OF TELECOMMUNICATION LINKS FROM RADIATION EFFECTS

JANUARY 1994

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FOREWORD

Among the responsibilities assigned to the Office of the Manager, National Communications System, is the management of the Federal Telecommunication Standards Program. Under this program, the NCS, with the assistance of the Federal Telecommunication Standards Committee identifies, develops, and coordinates proposed Federal Standards which either contribute to the interoperability of functionally similar Federal telecommunication systems or to the achievement of a compatible and efficient interface between computer and telecommunication systems. In developing and coordinating these standards, a considerable amount of effort is expended in initiating and pursuing joint standards development efforts with appropriate technical committees of the International Organization for Standardization, the International Telecommunication Union-Telecommunications Standards Sector, and the American National Standards Institute. This Technical Information Bulletin presents an overview of an effort which is contributing to the development of compatible Federal and national standards in the area of telecommunication link protection. It has been prepared to inform interested Federal and industry activities of the progress of these efforts. This report supplements NCS Technical Information Bulletin 93-9, Protection of Telecommunication Links from Physical Stress, June 1993. Any comments, inputs or statements of requirements which could assist in the advancement of this work are welcome and should be addressed to:

Office of the Manager
National Communications System
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701 S. Court House Road
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TECHNICAL REPORT

PROTECTION OF TELECOMMUNICATION LINKS FROM RADIATION EFFECTS

JANUARY 1994

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EXECUTIVE SUMMARY

PURPOSE OF THIS REPORT

This report describes measures that are intended to provide a *baseline* level of protection for links of public telecommunication networks (PTNs) against certain radiation effects. The measures are intended to establish foundation-level protection from damage caused by these radiation effects under typical geographic and local environmental conditions. The report should help define generally accepted practices, which are intended to meet the needs of public telecommunication networks.

The work results from a proposal by the National Communications System (NCS) to have the telecommunication industry develop a new national standard, "Protection of Telecommunication Links from Physical Stress and Radiation Effects." The NCS proposal has been accepted by ANSI-accredited Committee T1, Telecommunications.

This report supplements NCS Technical Information Bulletin 93-9, *Protection of Telecommunication Links from Physical Stress*, June 1993, and forms the technical basis and rationale for the radiation effects protection measures. It is to be used in support of a technical standards contribution to Committee T1.

BACKGROUND

The NCS is actively supporting several efforts of the telecommunication industry to help ensure the reliability of public networks during periods of electrical and physical stress. Central to these efforts is a series of nationally recognized standards that identify normally encountered stresses and define corresponding baseline protection measures. The measures are described in an interrelated group of national standards, each of which addresses a type of stress (electrical or physical) and a network category (center or link). These standards are being developed in Committee T1. The three standards listed below have already been published; two more are in preparation.

- ANSI T1.308-1990, *Central Office Equipment – Electrostatic Discharge Requirements*

- ANSI T1.313-1991, *Electrical Protection for Telecommunications Central Offices and Similar-Type Facilities*

- ANSI T1.316-1992, *Electrical Protection of Telecommunications Outside Plant.*

This report addresses the content of the proposed baseline standard, which will include protection from radiation effects on communication links interconnecting the centers of a

public telecommunication network. It forms part of the technical basis for that standard, which is being developed in Committee T1.

SCOPE OF THIS REPORT

The baseline protection measures of this report apply to the telecommunication *links* that interconnect environmentally controlled *centers* of PTNs. The links are fiber-optic or copper-conductor cables of the trunk, feeder, and local distribution plant. They include connection and repeater points that are on pedestals or poles, or in manholes, and that are not environmentally controlled. The terminations of the links in environmentally controlled buildings are included, but the buildings themselves and their contents are excluded. The protection measures are concerned primarily with the generic features of telecommunication links rather than with specific network equipment or components.

The protection measures are intended to be applied to the installation of new telecommunication facilities, and not necessarily to the replacement of existing installations. The measures include information for the design and construction of aerial, buried, and underground telecommunication plant, and apply to all providers of public telecommunication network services, including local exchange carriers and interexchange carriers. The measures do not apply to communication links serving specialized locations, such as the high-voltage environment that may be encountered at power-generating stations and substations.

RADIATION EFFECTS

The protection measures described in this report address protection against the following types of radiation effects:

- Electromagnetic Interference
- Gamma Radiation
- Solar Magnetic Storms.

PROPOSED MEASURES

The proposed protection measures are presented in categories according to the type of radiation effect that is addressed. The measures are specific and quantitative. Their intent is as follows, in abbreviated form.

Electromagnetic Interference

The measures address electromagnetic interference by specifying that electronic equipment in telecommunication links have a baseline level of immunity to electromagnetic fields. The measures cover immunity from broadband and continuous narrowband sources. Continuous narrowband sources include high-power radio transmitters, portable transmitters, and nearby electronic equipment. Examples of broadband sources are electric motors, combustion engines, and electrostatic discharges.

The measures set a level of immunity to narrowband electric fields over the frequency range 10 kHz to 10 GHz, and specify immunity to narrowband magnetic fields over the frequency range 60 Hz to 30 kHz. A measure of immunity to broadband sources is provided by requiring electronic equipment to be immune to indirect electromagnetic discharges applied in accordance with national and international standards.

Gamma Radiation

Gamma radiation can cause increased attenuation in optical fibers. This attenuation effect can be made acceptable at baseline threat levels by minimizing the impurities and imperfections in the fibers. The protection measure requires the use of fibers having sufficiently low attenuation, and is based on EIA/TIA standards covering optical fibers.

Solar Magnetic Storms

Solar magnetic storms occur with varying degrees of intensity about every 11 years, causing low-frequency voltage differences in the earth. These storms have caused widespread outages on ac power systems that power telecommunication links, and the possibility of recurrence is probably the most critical threat to the continuity of communications. The corresponding protection measure reinforces the need for sufficient battery reserve time and standby engine-alternators for telecommunication links.

Continuity of service is further addressed by a measure requiring links that have a conductive connection to earth to operate properly in the presence of ±3 volts between the ends of the link over the duration of the solar storm.

A final measure addresses the possibility of overheating surge protectors on the links at the telecommunication center. This possibility is dealt with by requiring that such surge protectors safely conduct low levels of current for the duration of the solar event.

BASELINE STANDARDS FOR PROTECTION OF TELECOMMUNICATIONS LINKS FROM RADIATION EFFECTS

TECHNICAL REPORT

1.0 INTRODUCTION

1.1 Purpose of This Report

The purpose of this report is to describe cost-effective measures that reduce radiation effects on telecommunication links in Public Telecommunications Network (PTN) systems. It has been prepared in support of a Standards Committee T1 – Telecommunications Standard Project Proposal, approved as Project TIYI-27 (Reference 1.1-1). These measures are intended to form the basis of a national standard that establishes foundation-level protection from damage caused by radiation effects under typical geographic and local environmental conditions. This baseline standard should help in defining generally accepted practices to meet the needs of public telecommunication networks. This report is a supplement to the National Communications System (NCS) Technical Information Bulletin 93-9, *Protection of Telecommunication Links from Physical Stress*, June 1993.

Reference for Section 1.1

1.1-1 *Protection of Telecommunication Links from Physical Stress and Radiation Effects*, Standards Committee T1, Telecommunication Standard Project Proposal T1 LB 273 Revised, January 16, 1992.

1.2 Policy Statement - NCS Mission

Executive Order 12472 defines the mission of the National Communications System (NCS), in part, as the coordination of the planning for, and provision of, National Security Emergency Preparedness (NSEP) communications for the Federal Government under all circumstances, including crises or emergencies. Key responsibilities of the NCS are: (1) to seek development of a national telecommunications infrastructure that is survivable, responsive to NSEP needs of the President and the Federal Government, capable of satisfying priority telecommunications, and consistent with other National policies; (2) to serve as a focal point for joint industry-government NSEP telecommunications planning; and (3) to establish a joint Industry-Government National Coordinating Center. This report supports the National Security Telecommunications policy as stated in NSDD-97, "...the national telecommunications infrastructure must possess the functional characteristics of connectivity, redundancy, interoperability, restorability, and hardness necessary to provide a range of telecommunication services to support essential national leadership requirements."

1.3 Scope of This Report

1.3.1 Covered Telecommunication Plant

The protection measures of this report apply to the telecommunication *links* that interconnect environmentally controlled *centers* of PTNs. The links are fiber-optic or copper-conductor cables of the trunk, feeder, and local distribution plant. The links include connection and repeater points that are on pedestals or poles, or in manholes, and that are not environmentally controlled. The terminations of the links in environmentally controlled buildings, and their power sources, are included, but the buildings themselves and their contents are excluded (see Figure 1.3-1). The protection measures are concerned primarily with the generic features of telecommunication links rather than with specific network equipment or components.

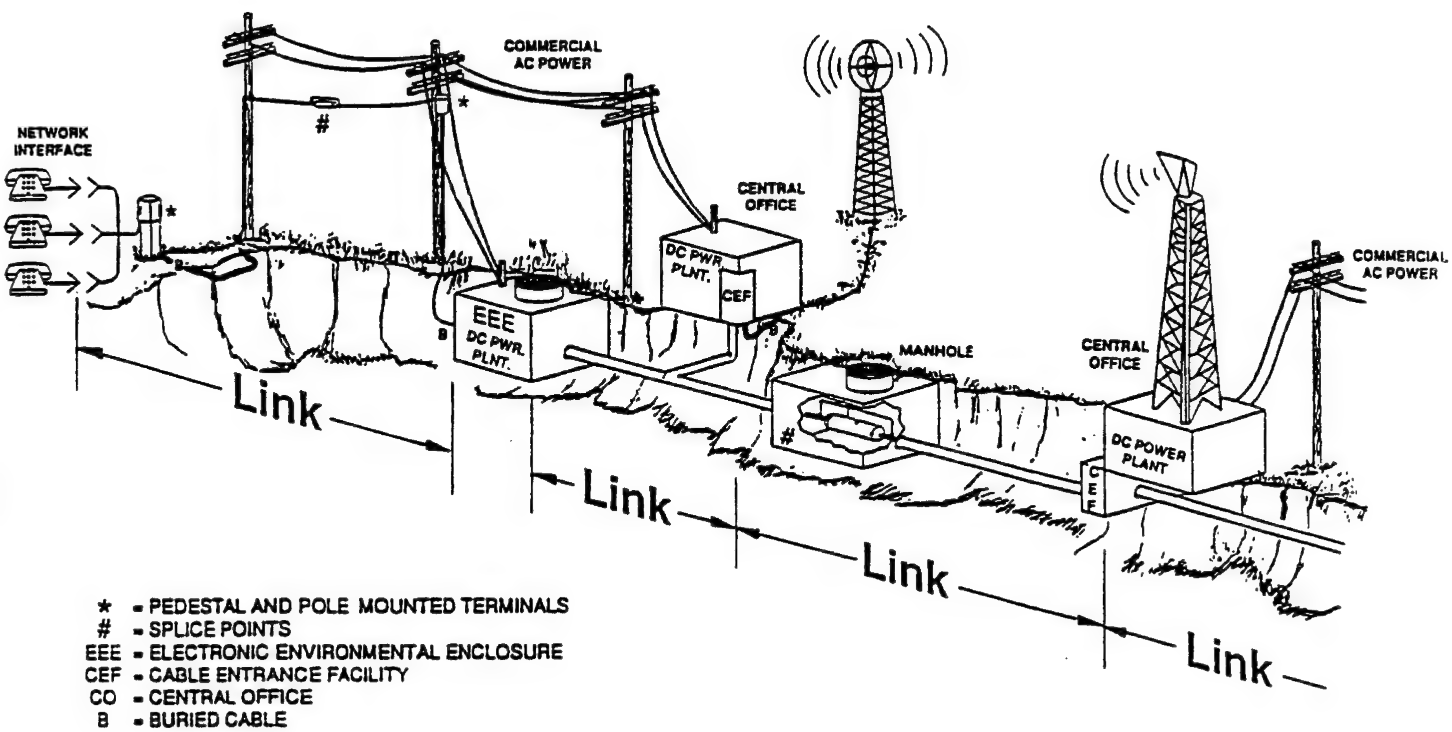

Figure 1.3-1. Telecommunication Links in the Network

1.3.2 Covered Radiation Effects

The protection measures described in this report address protection against the following types of radiation effects:

- Electromagnetic Interference
- Gamma Radiation
- Solar Magnetic Storms

The baseline protection measures identified in this report are intended to be reasonable and practical to implement. It is assumed that link facilities are provided with *electrical* protection in accordance with national standards (References 1.3-1, -2, and -3). Because of the complex and diverse nature of public telecommunication networks, not all measures identified here can be applied at all locations with the same level of effort. Wherever possible, alternative techniques and technical judgments are permitted to help ensure that the proposed measures are cost-effective. In all cases, reference material was obtained only from unclassified and nonproprietary technical literature.

1.3.3 Application

The protection measures are intended to be applied to the installation of new telecommunication facilities, and not necessarily to the replacement or repair of existing installations. The measures include information on the design and construction of aerial, buried, and underground telecommunication plant, as appropriate, and apply to all providers of public telecommunication network services, including local exchange carriers and interexchange carriers. The measures do not apply to telecommunication links serving specialized locations, such as the high-voltage environment that may be encountered at power-generating stations and substations.

References for Section 1.3

1.3-1 *Electrical Protection of Telecommunications Outside Plant,* ANSI T1.316-1992.
1.3-2 *1993 National Electrical Code,* ANSI/NFPA 70-1993.
1.3-3 *1993 National Electrical Safety Code,* IEEE Std. C2-1993.

1.4 Organization of This Report

Physical aspects of the threats and stresses are briefly discussed in this chapter to provide background information. Protective measures for each threat are then discussed in separate chapters, each of which contains a statement of the protective measures, followed by a discussion of the rationale for the measures, and references.

1.5 Description of Threats

Before an understanding can be established of the type of protection measures that would be effective against physical stresses, it is helpful to have a description of the nature of the stresses. These stresses are both naturally occurring and man-made.

An overview of physical stresses on fiber-optic long-distance networks has been made available as a multi-tier specification by the NCS (Reference 1.5-1). That overview is augmented by this technical report, which also considers radiation effects on copper-conductor cable links. It includes effects that are not emphasized in the multi-tier specification, but which telecommunications providers have found to be significant. Radiation effects that are considered to be extraordinary events, beyond the scope of a baseline standard, are not included in this technical report.

The radiation effects are described here in the context of what is normally encountered in the environment of generalized telecommunication links. No attempt is made to discuss or treat extraordinary events with any heroic mitigative measures. Normally encountered threats are covered in the context of reasonable and practical mitigative measures for a baseline standard that provides foundation-level protection from radiation effects under typical geographic and environmental conditions.

The following sections of this chapter provide brief descriptions of the basic radiation effects; more details are available in the referenced documents and in the extensive literature in engineering and scientific journals.

Reference for Section 1.5

1.5-1 *Multitier Specification for NSEP Enhancement of Fiber Optic Long-Distance Telecommunication Networks,* National Communications System (NCS TIB 87-24) and National Telecommunications and Information Administration (NTIA Report 87-226), December 1987.

1.6 Electromagnetic Interference

Narrowband electromagnetic emissions from high-power radio transmitters, portable transmitters, and nearby electronic equipment may cause Electromagnetic Interference (EMI) to electronic equipment in telecommunication links (e.g., multiplexers, repeaters, optical network units). Examples of high-power transmitters are AM broadcast, television, FM broadcast, and radar. The effects of EMI range from audible noise on the link (e.g., demodulation of an RF signal in an abnormal surge protector) to shutting down high-capacity service (e.g., many bit errors in an optical repeater).

Another EMI threat to telecommunication links is caused by broadband electromagnetic sources. Examples of broadband sources are electric motors, combustion engines, and

electrostatic discharges. These sources generate broadband emissions because of the impulsive nature of the signals.

1.6.1 Narrowband Electric and Magnetic Field Immunity

Narrowband electric-field sources are those with radiating frequencies between 10 kHz and 10 GHz. These fields include a mixture of emissions from licensed transmitters (e.g., AM and FM broadcast, television, amateur radio, and police/emergency communications).

The maximum permissible transmission power for new AM broadcast stations is 50 kW; for FM broadcast stations, 100 kW; and for TV broadcast stations and radar, 5 MW (Reference 1.6-1). The maximum permissible transmission power for private shortwave stations is 50 kW. It is important to note that these values are the input power to the antenna and not the effective radiated power in the main beam of the antenna. The effective radiated power can be larger because it includes the antenna gain.

The increased use of portable transmitters (e.g., cellular telephone, VHF business band, and Personal Communications Services) is also a threat to the telecommunication links. Although these are low-power narrowband transmitters, the electromagnetic fields close to one of these transmitters are considerable, since field magnitude is inversely proportional to the square of the distance.

ANSI C63.12 (Reference 1.6-2) recommends that general-purpose electronics have an electric-field immunity capability of at least 1 volt per meter, but it also states that for reliable operation at all locations, the level should be higher. Equipment in telecommunication links can be providing services of a critical nature, and therefore can be expected to have a higher level of immunity. For example, the immunity specification for AT&T 1ESS™ digital switches has been 2 volts per meter from 10 kHz to 1 GHz (Reference 1.6-3). This immunity limit has been in place for several years and appears reasonable, considering that licensed radio services produce an electric field strength of 2 volts per meter at moderate distances from the antenna (1.1 km for a 50-kW station). A limit of 1 volt per meter would restrict the telecommunication-link site to be more than 2.1 km from the same transmitter.

Collocated ancillary electronic equipment may be another source of EMI to electronic telecommunication-link equipment. This ancillary equipment may be located within 1 meter of the telecommunication link. The increased amount of electronic equipment (nonintentional radiators) near telecommunication links, and intentional radiators (e.g., broadcast radio stations) in the vicinity of telecommunication links, augment the electromagnetic field strength incident on these links.

The electromagnetic waves generated by the foregoing sources can cause EMI to electronic telecommunication-link equipment (e.g., digital/optical repeaters, optical network units,

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multiplexers/demultiplexers). The interference may range from audible noise (broadcast demodulation) on voiceband leads to shutting down of repeaters. Audio demodulation may occur at operated carbon-block protectors in the telecommunication links. A T1 repeater may be completely incapacitated by EMI that causes it to receive, or perceive to receive, excessive bit errors in a short period of time.

Electromagnetic interference to telecommunication links is important to telecommunication network users since it can make the network unusable. Therefore, baseline immunity standards are necessary for the electronic equipment in the telecommunication links to reduce the possibility of radio interference from intentional sources (e.g., licensed transmitters) and nonintentional sources (e.g., collocated electronic equipment).

1.6.2 Broadband Field Immunity

Examples of sources of broadband interference include combustion engines, electric motors, faulty power-line insulators, and electrostatic discharges. Electrostatic discharges (ESDs) are considered to be broadband events with energy distributed in the frequency range 10 MHz to 10 GHz. Broadband interference generated by sparking typically has most of its emissions below 500 MHz.

It is important that electronic equipment in telecommunication links have a baseline level of immunity to such sources because of the uncontrolled environment of its operation. Repeaters for digital carrier systems commonly are located at the base of a wooden pole, in a pedestal, or in a busy commercial or residential area, where they may be exposed to broadband interference from nearby power tools, gasoline engines, or electrostatic discharges. Such broadband interference can have a large effect on digital equipment, since a spark (broadband signal source) can be interpreted by the digital equipment as the leading edge of a bit.

References for Section 1.6

1.6-1 Federal Communications Commission, Part 73 of Chapter 1 of Title 47 of the Code of Federal Regulations.

1.6-2 ANSI C63.12-1984, *Recommended Practice on Procedures for Control of System Electromagnetic Compatibility.*

1.6-3 *RFI Shielding*, AT&T Practice BSP 760-220-100.

1.7 Gamma Radiation

1.7.1 Description

Exposure of optical fibers to nuclear radiation can be detrimental to the usefulness of the fiber for signal transmission. Optical fibers are exposed to a wide range of ionizing radiation from

naturally occurring radioactive sources in terrestrial installations, and in some installations fibers may be exposed to radiation from nuclear reactors. The potential for radiation-induced loss in the fiber must be considered in evaluating the long-term reliability of optical transmission systems.

1.7.2 Origin of Gamma Radiation

The three primary natural sources of radiation in the earth's upper crust are uranium (U), potassium (K), and thorium (Th). It was estimated that under normal ambient conditions, a fiber-optic cable buried at 1 meter receives 150 mrad/year (Reference 1.7-1). This was based on average soil concentrations of 3 ppm U, 2 percent K, and 6 ppm Th. An upper bound dose rate of 500 mrad/yr was estimated for roughly 95% of the continental US. This concentration typically occurs over small areas; therefore, it is unlikely that an entire long-haul or trunk cable would be exposed to a dose rate of 500 mrad/yr. A 150 mrad/yr dose rate is representative of most of the underground environments in which fiber-optic cable is deployed (Reference 1.7-2).

The potential threat from man-made gamma radiation sources must be considered within the context of the National Security/Emergency Preparedness (NSEP) environments for fixed plant telecommunication links. Four specific environments of NSEP telecommunication are considered (Reference 1.7-3):

- peacetime natural disasters
- crisis management
- limited conventional war
- nuclear war.

Each of these environments presents special concerns to providers of NSEP telecommunication links. This study assumes that of the four environments, the first two are baseline and the others are above baseline. The baseline communication measures should help to assure survivability in the environments of peacetime natural disasters and crisis management. Crisis management situations include international incidents such as hijackings and terrorist events, domestic incidents such as the accident at Three Mile Island (TMI), and third-party military actions that may result in heightened tensions at home or abroad. The most stressing environment for the fiber encompasses the fallout from a reactor malfunction.

This study does not consider as a baseline threat the potential radiation effects of the same magnitude as witnessed at the Chernobyl Nuclear Reactor Station explosion. However, an accident on the order of TMI reactor number 2 (TMI-2) is considered as baseline for compliance with the NSEP requirements for crisis management. At TMI-2, only the noble gases and volatile fission products from the damaged reactor core were released in significant quantities. The radiation level at the adjacent reactor TMI-1 facility at the time of the accident was measured at 100 mrad for the 24-hour period immediately after the shutdown of the reactor (Reference 1.7-4).

1.7.3 Effects on Telecommunication Links

For most long-haul and interexchange telecommunication lines, including feeder lines from the central office to neighborhood nodes and large business areas, optical fiber is the transmission medium of choice. Deployment of fiber in the feeder and distribution networks is growing rapidly each year. These systems use conventional single-mode fiber predominantly in the 1.3-µm window; however, the 1.55-µm window is widely used for long-haul networks when the system allocation for the fiber power budget cannot be met by the 1.3-µm window. Multimode-fiber applications have been limited to short-length optical data links between buildings and to premises wiring in "smart" buildings.

The novelty of optical communication systems is that the signaling rates are high and the medium is immune to interference from electromagnetic fields. It is enticing to conclude that fiber-optic transmission links are not subject to degradation due to radiation. Specific studies by E. J. Friebele (Reference 1.7-5) and others offer a body of literature that demonstrates the radiation-induced effects in fibers. Exposure of optical fibers to ionization radiation causes two basic interactions to occur: electrons can be released by ionization, or atoms can be displaced by elastic scattering. Most of the electrons generated as a result of ionization ultimately recombine with holes, which are also generated by ionization, but some small fraction of the electrons can become trapped at defect sites and cause absorption at the mid-infrared wavelengths commonly used for data transmission (0.85, 1.3, and 1.5 µm) (Reference 1.7-3). This is the primary mechanism for radiation-induced loss in optical transmission systems. The radiation sensitivity of single-mode fibers, then, is determined primarily by defects that form in the core and, to a much lesser extent, by defects in the cladding.

1.7.3.1 Induced Losses in Optical Fibers from Terrestrial Radiation

Today, long-haul, trunk, and feeder plant is more and more becoming connected with single-mode fiber. Single-mode fiber systems exposed to an average terrestrial dose rate of 150 mrad/year are expected to experience increases in attenuation for a span of 30 km as shown in Table 1.7-1 (Reference 1.7-1).

Table 1.7-1. Added Span Loss for 30-km Span, 20-year Exposure, Standard Fiber

Operating Wavelength	Dose Rate	
	150 mrad/yr	500 mrad/yr
1.3 µm	0.04 dB	0.15 dB
1.5 µm	0.06 dB	0.21 dB

The estimates given in Table 1.7-1 were based on the worst-case condition of exposing the full span to the dose rates shown. Also, the test data were based on fibers commercially produced in the 1987 time frame. The improvement in fiber fabrication is evident by the availability of fiber-optic cables with a maximum attenuation grade of 0.35 dB/km at 1.3 μm. Since 1987, the median attenuation grade of commercially available fibers has been reduced by approximately 0.1 dB/km. This is a good indication of a substantial reduction in the defects in the core that determine the sensitivity of the fiber to radiation (Reference 1.7-5 and others). Therefore, today's fibers are less sensitive to radiation than those whose values are indicated in Table 1. However, even those values of attenuation are insignificant compared to the loss of an unexposed fiber, and are well within the loss budget of the system. Therefore, the incremental added loss for any conventional single-mode system poses no threat to terrestrial networks.

1.7.3.2 Induced Losses in Optical Fibers from a Nuclear Reactor

In addition to inherent radiation-induced losses from the environment, consideration must be given to the possible added losses to the optical link from reactor radiation sources. The expectation is that the protection measures afforded personnel by the shielding will not be less than the allowable limits based on the Federal dose limits for occupational workers in a nuclear-reactor power plant. Details of these limits are given in Chapter 3, Table 3.1.

Under normal operating conditions, the radiation exposure of the optical link will be less than the exposure levels of the personnel. In some cases, the local area communication link from the nearest distribution point may terminate inside the power plant facility. Assuming a worst-case condition that the fiber may be routed in the plant and the Planned Special Exposure of 40 rem takes place and coincidentally exposes the inside fiber segment to the total radiation dose, the added attenuation loss for this single event is less than the environmental radiation dose of 150 mrad/yr. The added loss may not be measurable with current field-deployable optical measurement equipment such as an optical-fiber time-domain reflectometer (OTDR).

For a worst-case condition, if a reactor accident releases radiation at the TMI-2 level of 100 mrad for the 24-hour period (Reference 1.7-4), the cumulative total dose to the optical fiber must be considered. Based on the effects of gamma radiation on attenuation from natural sources, the expected attenuation increase of the fiber exposed to 100 mrad will be 0.00007 dB/km. It is not likely that more than 1 km of the fiber will experience this radiation dose. At that dose rate, the fiber must be exposed to this radiation for 1 year before a measurable amount of attenuation (0.025 dB) increase is detected in the fiber. Even a 20-year exposure to this dose rate will only increase attenuation by about 0.5 dB in the fiber link.

1.7.3.3 Transmission Link

Commercial fiber-optic cables installed today use single-mode fiber. The design parameters of the system must include the attenuation of the fiber and connectors, detector sensitivity, and aging characteristics of the system. The typical power budget for a link includes about 2 dB

for component degradation. Based on the typically deployed transmission link, the induced loss in the fiber caused by terrestrial gamma radiation effects should not be of concern and should not be considered as an additional degradation factor on the system. However, where the link must be installed near a nuclear reactor, a 1-dB degradation factor may be added to the link calculation to account for possible attenuation increases caused by prolonged exposure to radiation leakage that may occur if the reactor is damaged. In cases where alternate-route diversity exists, the 1-dB budget penalty should not be considered.

References for Section 1.7

1.7-1 J. B. Haber, *Proc. 1st MFOC Conf.*, Washington, DC, 1987, Pg. 87-90.

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1.8 Solar Radiation from Magnetic Storms

1.8.1 Description

Radiation from the sun during magnetic storms can affect telecommunication links of wire-line networks. Records show that such radiation effects have caused disruption of telecommunications, including shutdown of a long-haul carrier route, and a fire in a telecommunications office (Reference 1.8-1). Widespread interruption of ac power systems has also occurred (Reference 1.8-2).

1.8.1.1 Origin of Magnetic Storms

Magnetic storms on the sun have long been associated with currents in the mantle of the earth that can disturb wire-line telecommunications (References 1.8-3 and 1.8-4). The ultimate origin of these effects is solar activity. It occurs in a cycle that crests about every 11 years, but the cycle has been as short as 7 years and as long as 17. The occurrence and size of sunspots are at their greatest during these crests. Sudden changes in the intensity of the magnetic fields at the sunspots give rise to extremely bright solar flares, usually in the midst of large sunspot groups. These flares emit ultraviolet and particulate radiation (solar wind composed of ions and electrons), which may produce changes in the strength of the magnetic

field and the shape of the earth's magnetosphere (Reference 1.8-5). These changes, which can be 100 times greater than normal variations, are called *magnetic storms*. They occur about 1 day after a large flare passes over the sun's surface.

Although the physical processes are complex and vary for different storms, these magnetic disturbances have proven capable of causing strong currents in the earth's surface layers. The currents are conducted in an approximate east-west direction in the northern U.S., and have a magnitude that generally increases with geomagnetic latitude.

If a long conductor were to be connected to the earth and extended in an east-west direction, a voltage would be read between the earth and the free end of the conductor. This voltage depends on the resistance of the earth and is greatest where earth resistivity is high.

The relative risk of a large voltage drop has been estimated by Karsberg (Reference 1.8-3) to be the product of earth resistivity, the intensity of magnetic interference, and the cosine of the angle that the conductor makes with the direction of maximum voltage drop. The intensity of magnetic interference in the U.S. tends to increase with geomagnetic latitude, so the greatest voltages are likely to arise in the east-west orientation, at high latitudes, in areas where the earth resistivity is high.

1.8.1.2 Magnitude

Karsberg (Reference 1.8-3) estimates that the maximum voltage (V_M) arising between the ends of an aligned conductor during a magnetic storm is

$$V_M = 0.056 \rho I L$$

where

V_M is expressed in volts
ρ is the earth resistivity in 1000 meter-ohms
I is the intensity of magnetic interference in 10^{-3} Gauss
L is the length of the conductor in km.

As an example, with an earth resistivity of 1000 meter-ohms and a magnetic storm producing an intensity I = 5 mG, a conductor 1 km long would experience a voltage of about 0.3 volt. Of course, the magnitude of storms varies greatly, so this relationship is but a rough design guide. Furthermore, the linear dependence on resistivity based on an assumed uniform earth is especially crude; a layered-earth model for a particular installation produces a more reasonable estimate (References 1.8-5 and 1.8-6).

Various measurements and calculations have been made to estimate the voltage gradient in the earth during a magnetic storm. Results have indicated values as low as 1 volt per km and as high as 20 volts per km (Reference 1.8-7). According to information in Reference 1.8-5, a protection circuit for a specific long-haul telecommunication system would require a manual reset if the average voltage over 150 miles [241 km] exceeded 2.5 volts per mile [1.6 volts

per km]. Because service interruptions on such systems are infrequent, gradients above that level would be rare.

1.8.1.3 Frequency

The voltages occur at frequencies in the range 10^{-4} to 10^{-1} Hz, and they typically last for several minutes (References 1.8-2, -5, and -7). These characteristics are slow compared to the 60-Hz currents of power utility systems or the high frequencies used in telecommunications. Therefore, the voltages may be treated as dc.

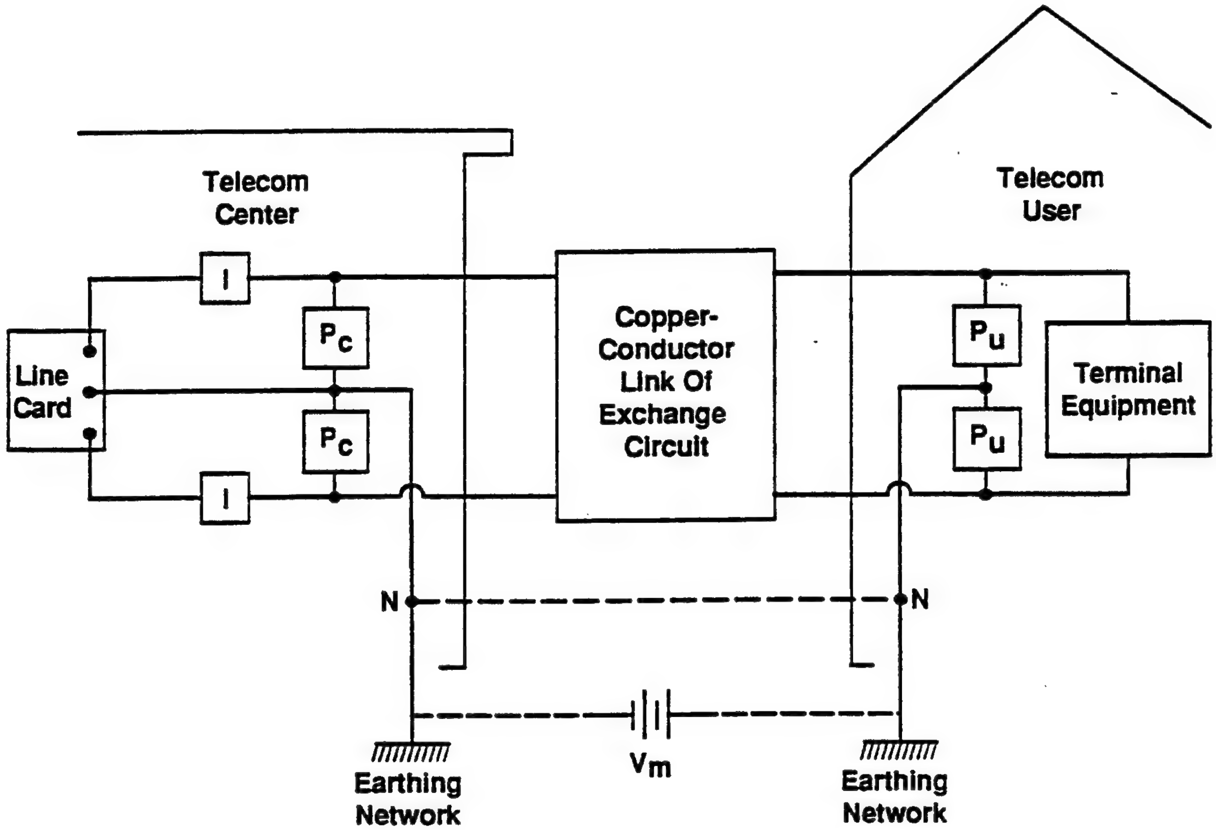
1.8.2 Effects on Wire-line Telecommunication Links

Copper-conductor telecommunication links can be affected indirectly during a magnetic storm if the ac supply from the power utility is interrupted (References 1.8-6, -7, and -8). The interruption of ac power may result from saturation of distribution transformers or from loss of communications that the power utility uses for relaying and network supervision. To help ensure continuity of telecommunication services, battery reserve time and the availability of standby engine-alternators must be adequate to provide power to the telecommunication links for the duration of these outages.

Telecommunication circuits themselves are directly vulnerable only to the extent that they have conductive connections to earth. Such connections may arise deliberately either for circuits that use earth-return signaling or for dc power sources that are connected to earth (Reference 1.8-6). On the other hand, earth connections may not normally be present, but may arise during a magnetic storm if surge protectors operate (Figure 1.8-1).

As shown in Figure 1.8-1, a representative exchange circuit is isolated from earth at the user's end, but may be connected to earth by means of the impedance of the line circuit at the telecommunications center. Consider the case where the neutral conductor (N) of the power utility does not interconnect the earthing networks of the two ends of the link. Such a situation is most likely to arise on long rural links or in areas where the power utility does not use a multigrounded neutral conductor in its distribution system.

During a magnetic storm, no current is conducted by the link unless the solar-induced voltage V_M exceeds the dc limiting voltage of the protector (P_u) at the user's premises. This limiting voltage may be as low as 265 volts, and since the center's battery voltage (50 volts) may add to the earth disturbance, a V_M of 215 volts may be enough to operate the protector. In that case, current is conducted by the earthing networks, the protector, the copper-conductor link, and the line circuit. Because the conducting voltage of a protector usually is lower than its dc limiting voltage, subsequent reduction of V_M to values greater than about 100 volts may not interrupt the circuit. If the voltage across the line circuit is sufficient, the protector (P_c) at the telecommunications center also operates.



V_m = Voltage Induced Between Earthing Networks By Magnetic Storm
N = Neutral Conductor Of AC Power Utility
I = Current Limiter
P_c, P_u = Surge Protector

Figure 1.8-1. Representative Telecommunications Exchange Circuit

While either surge protector is in the operated state, communications generally are not possible. However, if the magnitude and duration of the storm produce a current that is within the capabilities of the protectors and line circuit, communications are automatically restored after the solar disturbance passes.

In the extreme, magnetically induced current can overheat the protectors or line circuit, causing permanent damage (Reference 1.8-9). This event is not likely to occur. Even a worst-case magnetic storm producing 20 volts per km would require a link that is about 12 km long and optimally oriented. Furthermore, in many urban and suburban locales, there are connections to the power utility's neutral conductor (N of Figure 1.8-1) that provide a continuous metallic path between the earthing networks at the ends of the link. This path effectively short-circuits the source V_M. The shield of the telecommunications cable, if it is continuous from protector to protector, also provides this short-circuit function.

On circuits that power telecommunication links, such as those for powering loop carriers, both ends of the link may be connected to earth by means of the terminating impedance. These connections obviate the need for protectors to operate in order to create a conductive path. However, even in this case, connections to the power utility's neutral conductor or to a continuous cable shield are often present and effectively reduce the stress on the components of the link to negligible levels.

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2.0 ELECTROMAGNETIC INTERFERENCE

2.1 Protection Measure Recommendation

2.1.1 Narrowband Electric-Field Immunity

Each level in this section is the RMS value of a test signal that corresponds to the peak of the envelope over the frequency range of 10 kHz through 10 GHz. For frequencies in the range of 10 kHz to 1 GHz, the test signal shall be 80 percent amplitude modulated with a 1-kHz tone. For the frequency range of 1 GHz to 10 GHz, the test signal shall be pulse-modulated, with the modulating signal having a 0.1-μs pulse rise time, a 1-μs pulse width, and a 1-kHz pulse repetition rate. In addition to the swept frequency ranges specified in this section, the equipment under test (EUT) should also be tested at the discrete frequencies shown in Table 2-1 for at least 1 minute at each frequency.

Table 2-1. Specific Test Frequencies

Source	Frequency (MHz)
LORAN C	0.1
DS1	0.772
AM Broadcast	1.544
Amateur Radio	4
Amateur Radio	14.2
Citizens Band (CB)	27
Television Channel 2	57
FM Broadcast	100
Television Channel 11	201
Television Channel 52	701
Public Service(Common Carrier)	6197.2
EUT Clock Frequencies	Frequencies are dependent on particular equipment

Electronic telecommunication-link equipment shall perform properly when subjected to the levels of electric-field strength given in Table 2-2. This test shall be done with the EUT configured as in typical operation and maintenance.

Table 2-2. Immunity Requirement for Radiated Narrowband Electric Fields

Frequency (MHz)	Electric Field Strength (dBμV/m)
0.01 to 0.024	140
0.024 to 0.12	$107.6 - 20\log_{10}f$
0.12 to 10,000	126

These limits are plotted in Figure 2-1. If the electronic telecommunication-link equipment is located within 3 km of high-powered transmitters, the electronic telecommunication-link equipment shall perform properly when subjected to electric fields of 140 dBμV/m (10 volts per meter) over the frequency range of 10 kHz through 10 GHz. This test shall be done with the EUT configured as in typical operation and maintenance.

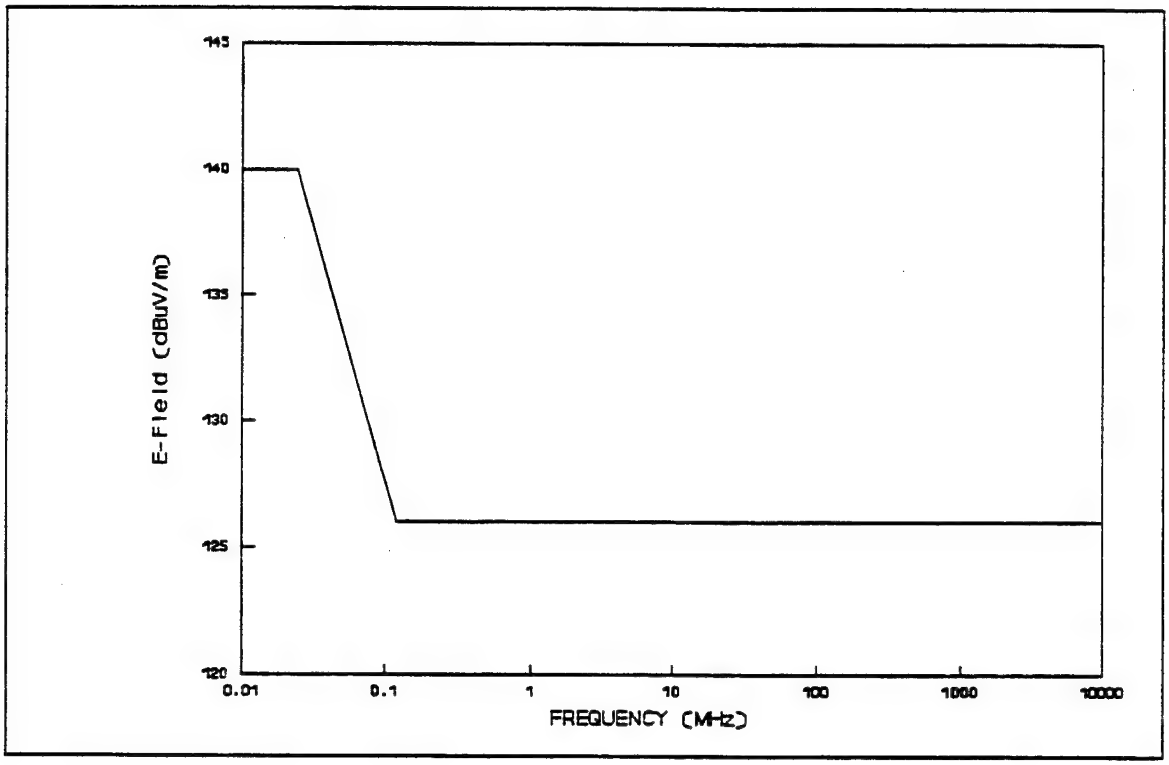

Figure 2-1. Plot of Narrowband Electric Fields vs. Frequency

2.1.2 Narrowband Magnetic-Field Immunity

The electronic telecommunication-link equipment shall perform properly when subjected to magnetic fields of a magnitude given by the equation

$$H = 50 - 20\log_{10}f$$

where H is in dBμA/m (RMS value of the test signal), and f is in MHz and ranges from 60 Hz through 30 kHz. This test shall be done with the EUT configured as in typical operation and maintenance.

2.1.3 Broadband Field Immunity

Broadband interference is that which is produced at a fairly constant energy level over a wide range of frequencies. Some sources of this interference are electric motors, combustion engines, and electrostatic discharges.

Indirect electrostatic Discharge (ESD) tests should be performed on electronic telecommunication-link equipment. The tests should conform to the standards for indirect application of discharges in ANSI T1.308-1990 (Reference 2-1), with the following modifications:

- Tests shall be conducted in accordance with the International Electrotechnical Commission (IEC) International Standard 801-2, second edition, 1991 (Reference 2-2).
- The contact discharge to the vertical and horizontal coupling planes shall be used with the test method described in Section 8.3.2 of IEC Standard 801-2, second edition, 1991 (Reference 2-2).
- The voltages associated with the severity levels of Section 5 of ANSI T1.308-1990 should be redefined to be the values that are specified for corresponding severity levels for contact discharges in Table 1.a of Reference 2-2.

2.2 Rationale

2.2.1 Narrowband EMI Sources

The increasing amount of electronic equipment (nonintentional radiators) and intentional radiators (e.g., broadcast radio stations) in the vicinity of telecommunication links augment the electromagnetic field strength incident on these links. The electromagnetic waves generated by these sources can cause electromagnetic interference (EMI) to electronic telecommunication-link equipment (e.g., digital/optical repeaters, optical network units, and multiplexers/demultiplexers). The interference may range from audible noise (broadcast demodulation) on voiceband leads to shutting down of repeaters. The nature of the

installations of equipment in links (e.g., on poles or in pedestals) makes them particularly subject to interference from a wide range of EMI sources.

Electromagnetic interference to telecommunication links is important because it can render the networks unusable. Therefore, baseline immunity standards are necessary for the electronic equipment in telecommunication links to reduce the possibility of radio interference from intentional sources (e.g., licensed transmitters) and nonintentional sources (e.g., collocated electronic equipment).

The immunity limits of this standard do not provide assurance of noninterference. The levels specified are based on ambient electromagnetic fields that may be present in telecommunication-link sites that are not exposed to strong fields from an intentional radiator. In particular, field strengths greater than the values shown in Figure 2-1 (which will be referred to as the 2 volts per meter [V/m] criterion) for electric fields may be present at some sites, and the 10 V/m limit is intended to accommodate those cases. If ambient field strengths exceed the 10 V/m limit, additional shielding of the structure that houses the telecommunication-link equipment may be needed.

2.2.1.1 Intentional Sources

Licensed radio services are the main source of electromagnetic signals that originate outside of telecommunication-link buildings. Emissions from licensed transmitters are mostly narrowband.

Figure 2-2 (page 2-10) is a plot of the 10 V/m (140 dBμV/m) radiated immunity criteria, the 2 V/m (126 dBμV/m) radiated immunity criteria (bottom line), and frequency bands where licensed radio services operate. Electronic telecommunication-link equipment should withstand the 10 V/m limit if they are to be installed in a high ambient field that is produced by those services.

Whereas Figure 2-2 shows the frequency ranges of radio services, it does not suggest the signal levels commonly found at telecommunication-link sites. A determinant of the field strength of RF signals from outside telecommunication-link sites is the distance to the transmitting antenna. Figures 2-3, 2-4, and 2-5 show the relationship between the power of an RF source (transmitting antenna) and the separation distance from the RF source to the telecommunication-link site to obtain a particular electric-field strength. (Section 2.3 describes the equations to generate Figures 2-3, 2-4, and 2-5.) The regions to the right of the curves represent combinations of distance and power that generate electric fields less than the curve legend. The curves represent the 10 V/m and 2 V/m limits for radiated immunity. Regions to the left of the curve represent distance and power combinations that exceed the electric-field immunity limit. For example, equipment that meets the radiated immunity 2 V/m limit at 1 MHz (middle of the AM broadcast band) may be located 1.1 km from a 50-kW AM broadcast station antenna (see Figure 2-3). If the equipment meets the 10 V/m limit at 1 MHz, it could be located 213 meters from the same antenna.

If in the example on the previous page the criteria were set to 1 V/m, the equipment would have to be located no less than 2.1 km from the antenna. The limitation of not installing electronic telecommunication-link equipment closer than 2.1 km from a 50-kW AM broadcast station reduces the number of possible sites for telecommunication links and/or requires consideration of adding shielding to the site.

The degree of attenuation provided by an enclosure or building that may enclose the telecommunication-link equipment at a particular frequency varies widely from one site to another. The shielding of a building also varies with the frequency of the RF signal, making it difficult to predict the building shielding precisely. Measurements (Reference 2-6) have identified central-office buildings that provide no attenuation, and sometimes even provide field enhancement. For these reasons the shielding (attenuation) provided by a building is not considered in the discussion of Figures 2-3, 2-4, and 2-5.

Field strengths of 10 V/m may be present at some locations — for example, 213 meters from a 50-kW nondirectional AM broadcast transmitter antenna, or 79 meters in front of an 8-dB gain amateur-radio antenna fed with 1.5 kW of peak envelope power. Therefore, it is possible to observe 10 V/m electric fields at telecommunication-link sites.

TR-1089 (Reference 2-7) specifies a radiated immunity level of 10 V/m. Equipment designs that meet this limit for radiated immunity (electric fields) in specific frequency bands have not experienced interference from radiated fields.

Considering that 10 V/m may be present at a telecommunication-link site and that the present objective of 10 V/m has safeguarded equipment from EMI, equipment to be operated in a severe electromagnetic environment should meet a radiated immunity limit of 10 V/m.

The 10 V/m limit for immunity is specified to prevent interference to equipment located within approximately 3 km of high-powered transmitters. This limit also provides an additional margin against interference from noncompliant equipment that may be nearby, and from spurious emissions from portable tools, appliances, welding equipment, etc.

2.2.1.2 Nonintentional Sources

Narrowband Electric Fields

The 2 V/m electric field immunity limit is intended to avoid interference from nonintentional sources within the telecommunication-link enclosure as well as from external sources typically encountered. From 10 kHz to 120 kHz, the 2 V/m electric field immunity criteria are derived from the ANSI C63.12 (Reference 2-4) electric field radiated emissions limit extrapolated to 3 meters (see Figures 2-6 and 2-7) with 20 dB added for margin. From 120 kHz to 10 GHz, the requirement is 2 V/m (126 dBμV/m).

Figure 2-7 is a plot of the lower frequency band (10 kHz to 800 kHz) of the 2 V/m radiated immunity limit (bold line). Also shown in Figure 2-7 is the derivation of the 2 V/m immunity limit: the electric field radiated emissions limit of C63.12 extrapolated to 3 meters, the emissions limit of C63.12 plus 20 dB, and a line at 2 V/m (126 dBμV/m). Only the low-frequency portion (10 kHz to 800 kHz) of the objective is plotted, for clarity.

Emissions from multiple ancillary equipment operating synchronously near each other generate more RF energy than one unit alone (Reference 2-4). Figure 2-8 is a plot of the incremental radiated emissions from a system versus the number of subsystems that compose the whole system. The plot shows the increment in radiated emissions level from a system composed of subsystems as additional subsystems are added. From this figure we can infer that when ten subsystems that meet the radiated emissions limits individually are located close together, the total emissions may be 18 dB above the emissions limit.

To take the addition of radiated emissions from subsystems into account, 20 dB are added to the low end (10 kHz to 120 kHz) of the emissions limit, and the resulting level is then used as the 2 V/m radiated immunity limit. This approach should protect equipment operating near multiple synchronously operating RF sources. It must be considered that electronic equipment would not typically have clocks operating at the frequencies considered here, so the margin may seem excessive. However, the 20-dB margin also takes into consideration that the radiating equipment may be closer than 3 meters. This proximity may result from equipment permanently installed at less than 3 meters, or from portable equipment such as electric drills or vacuum cleaners.

The 20-dB addition to the radiated emissions limit to arrive at the 2 V/m immunity limit applies only to frequencies below 120 kHz. At frequencies above 120 kHz, the radiated emission limit of C63.12 plus the 20-dB margin are below 2 V/m and would not offer enough protection from radiators outside the telecommunication-link enclosure.

Three other documents provide supporting information to justify the electric field immunity limits. First, according to Reference 2-6, 2.3 percent of central office buildings may be exposed to narrowband electric field strengths greater than 2 V/m in the AM band, 0.71 percent in the FM band, and 0.18 percent in the TV band.

Secondly, ANSI C63.12 (Reference 2-4) recommends a 1 V/m electric-field strength for immunity. However, the document also recommends that devices whose reliable operation at all locations is essential for any reason should be designed for higher immunity levels. Examples of higher immunity levels given in Reference 2-4 are 3.2 V/m, 10 V/m, 32 V/m, and 100 V/m.

Finally, predivestiture Bell System Practice BSP 760-220-100 (Reference 2-5) specifies a maximum allowable field strength of 2 V/m for 1ESS switches over the frequency range 10 kHz to 1 GHz. Above 1 GHz, the reference specifies a maximum allowable field strength of 10 V/m.

In summary, the electric-field immunity limit should be 2 V/m above 120 kHz for the following reasons:

- Licensed radio services produce 2 V/m electric-field strengths at moderate distances from the antenna (1.1 km for a 50-kW station). A 1 V/m limit would restrict the site of electronics to be more than 2.1 km from the same station.

- ANSI C63.12 recommends at least a 1 V/m limit, but also states that for reliable operation at all locations the level should be higher.

- The specification for 1ESS switches has been 2 V/m from 10 kHz to 1 GHz. From more recent experience with other systems, this specification is still valid.

Narrowband Magnetic Fields

The magnetic-field immunity limits are those that have been applied by the divested Bell Operating Companies to telecommunication equipment (Reference 2-7). Equipment that meets these limits has performed satisfactorily in diverse magnetic-field environments.

Mathematical analysis of representative power-line configurations, and the information provided in Chapter 8 of Reference 2-9, indicate that the magnetic-field immunity limit is not likely to be exceeded. In the case of distribution lines, the unbalanced currents are generally insufficient to generate the magnetic fields specified in the immunity limit. The limit is also not likely to be exceeded near transmission lines unless the phase current exceeds 650 amperes; for lines conducting these higher currents, a separation of 61 meters should suffice to remain within the limit.

The magnetic-field immunity limits assume that no fault conditions occur on the power lines. Such faults may cause fields that exceed the limits, but such conditions are expected to be of short duration, and interrupted operation may occur for baseline conditions.

2.2.2 Broadband EMI Sources

Broadband interference is that which is produced at a fairly constant energy level over a wide range of frequencies. Some sources of this interference are electric motors, combustion engines, and electrostatic discharges.

2.2.2.1 Nonintentional Sources

Discharge currents developed during ESD tests can have peak currents of tens of amperes, and can contain significant spectral components in the frequency range of 10 to 1000 MHz. The currents produce broadband electromagnetic fields. Thus, conformity of telecommunication-link equipment to standards for ESDs will also indicate that the equipment has an inherent degree of hardness to broadband electromagnetic fields.

ANSI T1.308-1990 (Reference 2-1) specifies that test procedures should be in accordance with the first edition (1984) of International Standard IEC 801-2 (Reference 2-2). Therefore, the tests categorized in Section 5.2 of ANSI T1.308-1990 as "Indirect Application of Discharge" are intended to be performed with a discharge in air between the ESD electrode and the ground plane. Although the first edition of International Standard IEC 801-2 specifies characteristics such as rise times and peak values for calibration of discharge currents, in practice it has been difficult to ensure that these characteristics are always realized during testing. For example, the air-discharge technique involves charging the ESD generator to the specified voltage and then moving the discharge electrode to the EUT until a discharge occurs. There is no practical way of controlling the motion of the electrode, and different approach modes have resulted in different rise times for the discharge current at a given voltage level. Also, the first edition of International Standard IEC 801-2 specifies that the discharges be applied to the earth reference plane. Application of the discharges to the earth reference plane does not simulate discharges to other nearby equipment that may generate vertical and/or horizontal electromagnetic fields.

In recognition of these and other deficiencies of air-discharge tests to the earth reference plane, the second edition of International Standard IEC 801-2 designates contact discharge to a vertical and horizontal coupling plane as the preferred test method. This method helps ensure repeatability and that the severity of the tests increases with the test voltage level. Also, the waveform that the second edition specifies for discharge current includes an initial current peak whose rise time (0.7 to 1 ns) is about 1/5 that of the single peak calibration waveform of the first edition. This increases both the high-frequency content of the current and the magnitudes of the fields produced by it. For these reasons, the direct-contact method to the vertical and horizontal coupling plane of Reference 2-2 has been adopted for this protective measure.

2.3 Explanation of Formulas for Calculating Electric Field Strength

Different formulas are used to calculate the worst-case electric field levels from AM, FM, and TV broadcast stations, and radar. The following formulas (Reference 2-8) give a reasonably accurate estimate of the electric field strength under ideal conditions for distances beyond 91 meters (near-field) from the antenna.

AM:

$$Field\ Strength(V/m) = 304.8\ \frac{\sqrt{ERP\ (kW)}}{d\ (m)}$$

FM, TV, and Radar:

$$Field\ Strength(V/m) = 182.9\ \frac{\sqrt{ERP\ (kW)}}{d\ (m)}$$

where

ERP is the effective radiated power in kilowatts, and
d is the distance to the antenna in meters.

These formulas assume a quarter-wave antenna radiating over smooth earth with perfect conductivity. Since these formulas assume hypothetically ideal conditions, they typically provide a conservative (high) estimate of the actual electric-field strength.

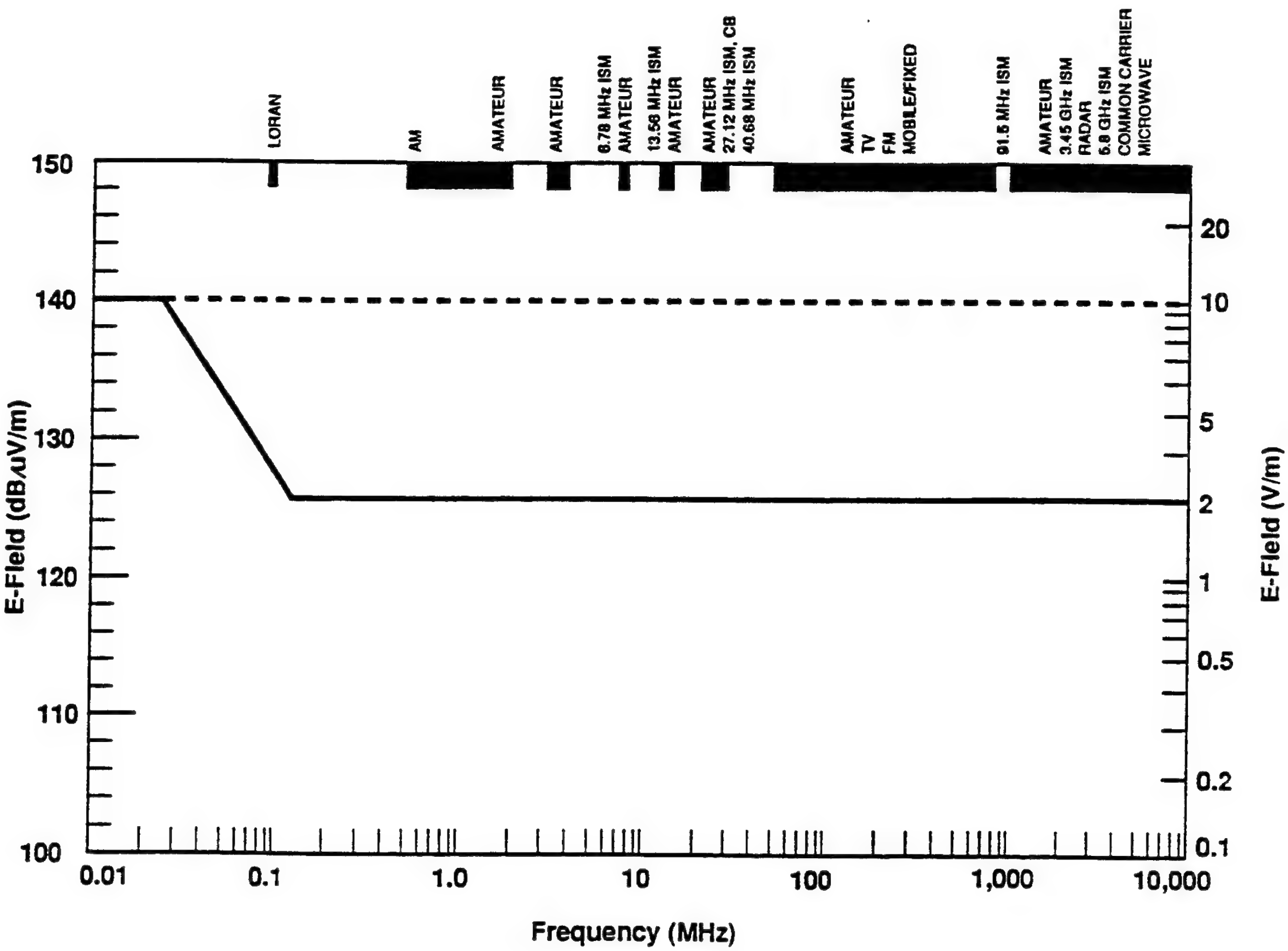

Figure 2-2. Radiated Immunity Criteria and Licensed Radio Service Bands

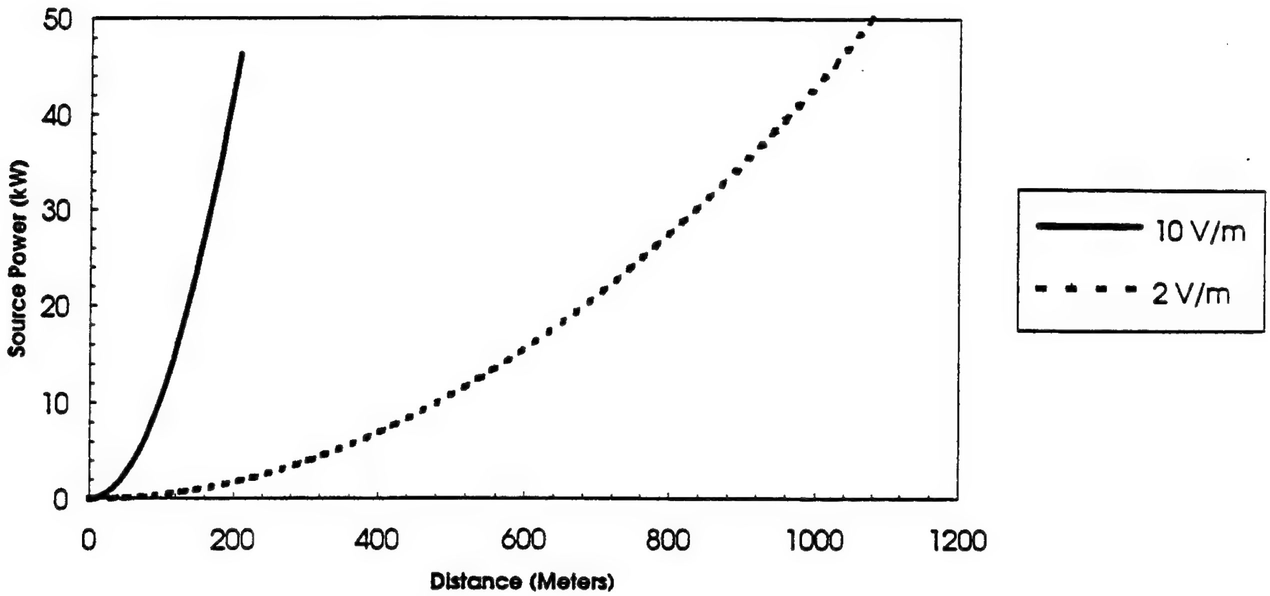

Figure 2-3. Relationship of RF Source Power and Distance from Source, AM Stations

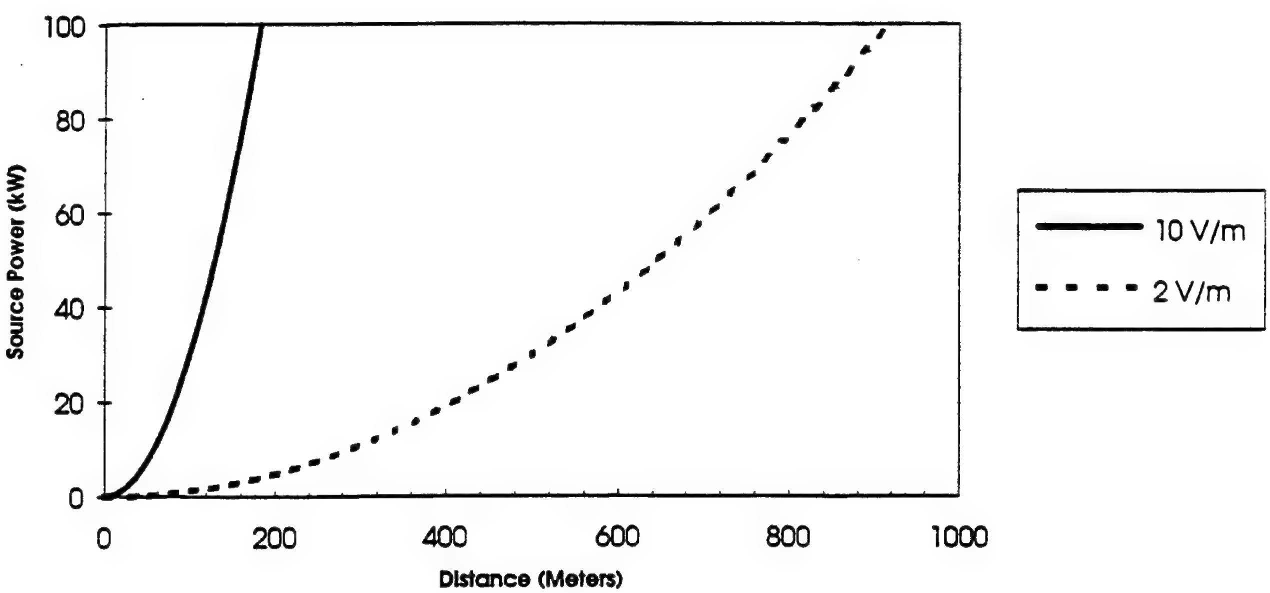

Figure 2-4. Relationship of RF Source Power and Distance from Source, FM Stations

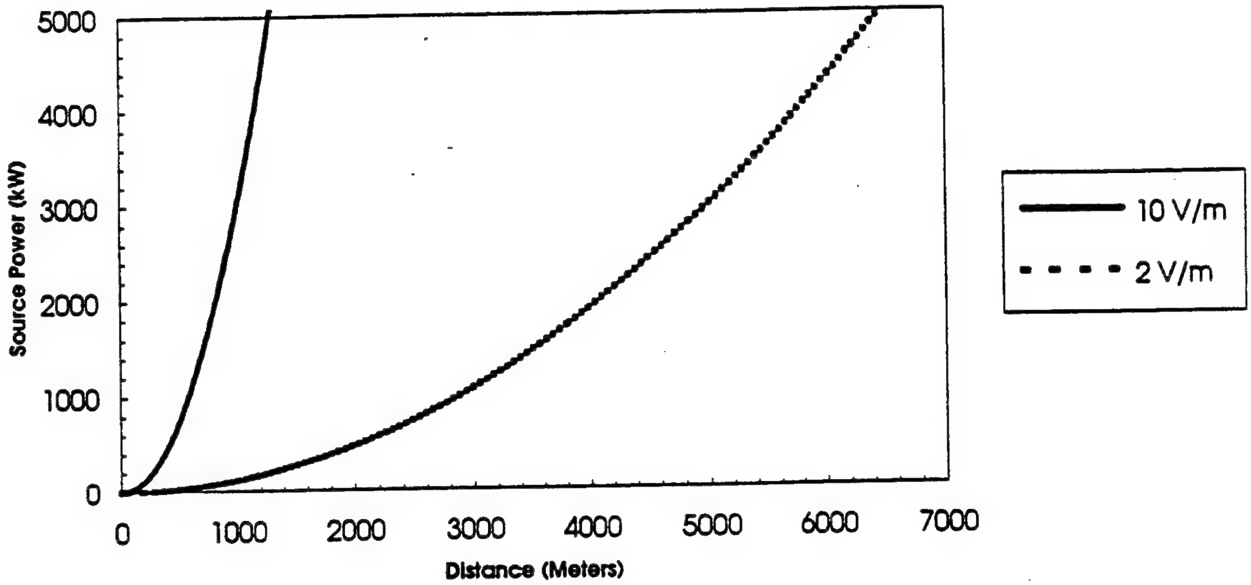

Figure 2-5. Relationship of RF Source Power and Distance from Source, TV and Radar

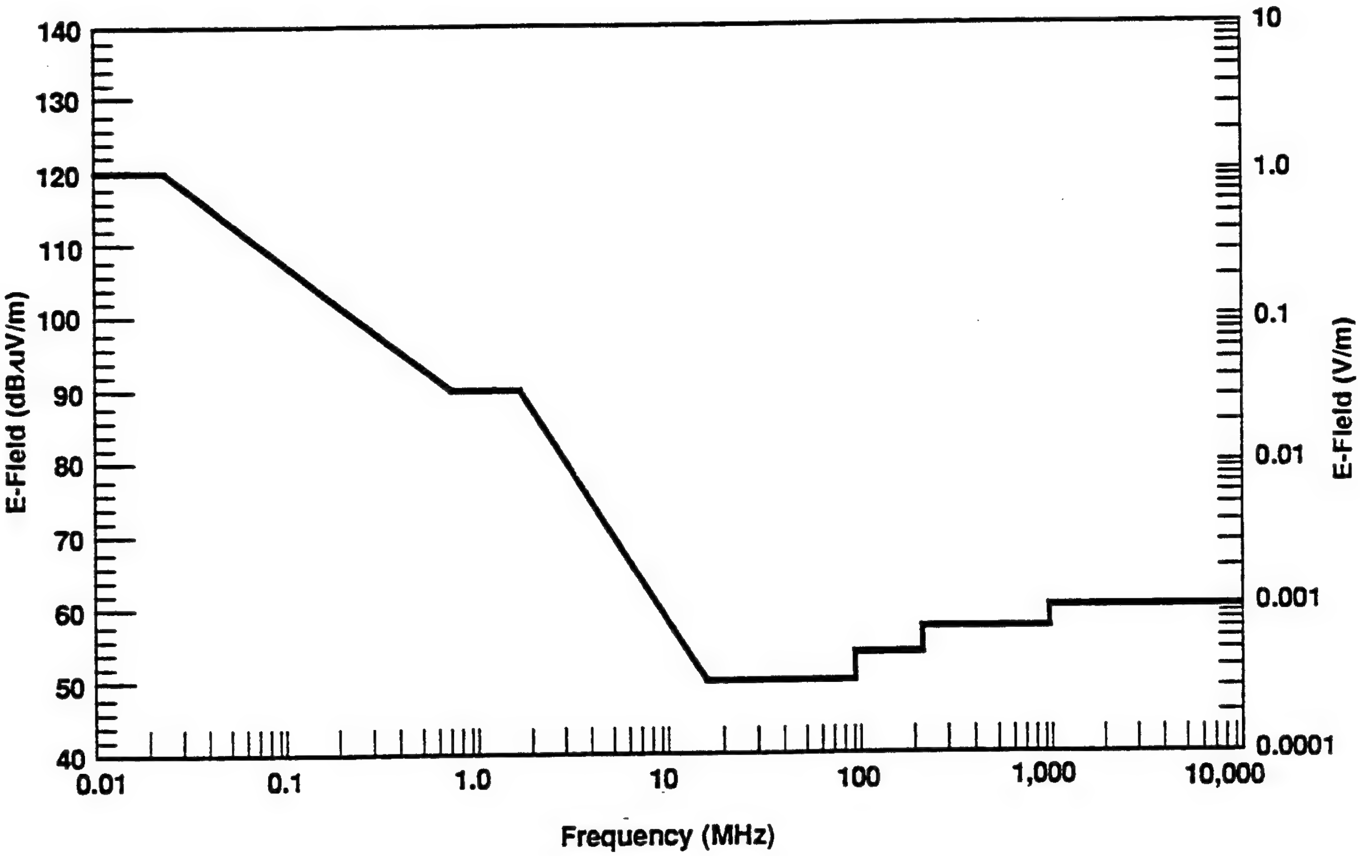

Figure 2-6. Radiated Emission Criteria (3 Meters)

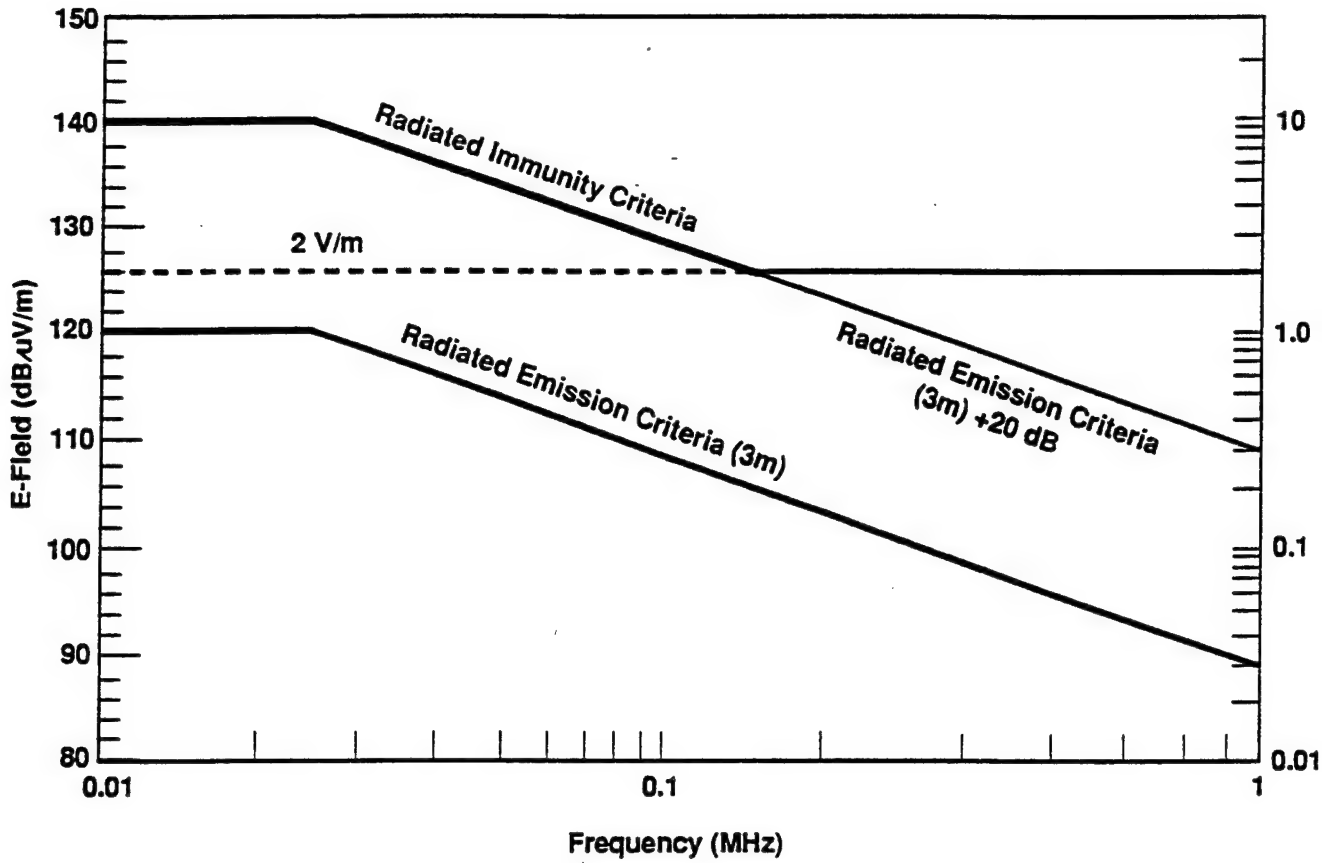

Figure 2-7. Low-Frequency Radiated Immunity Criteria (10 kHz to 800 kHz)

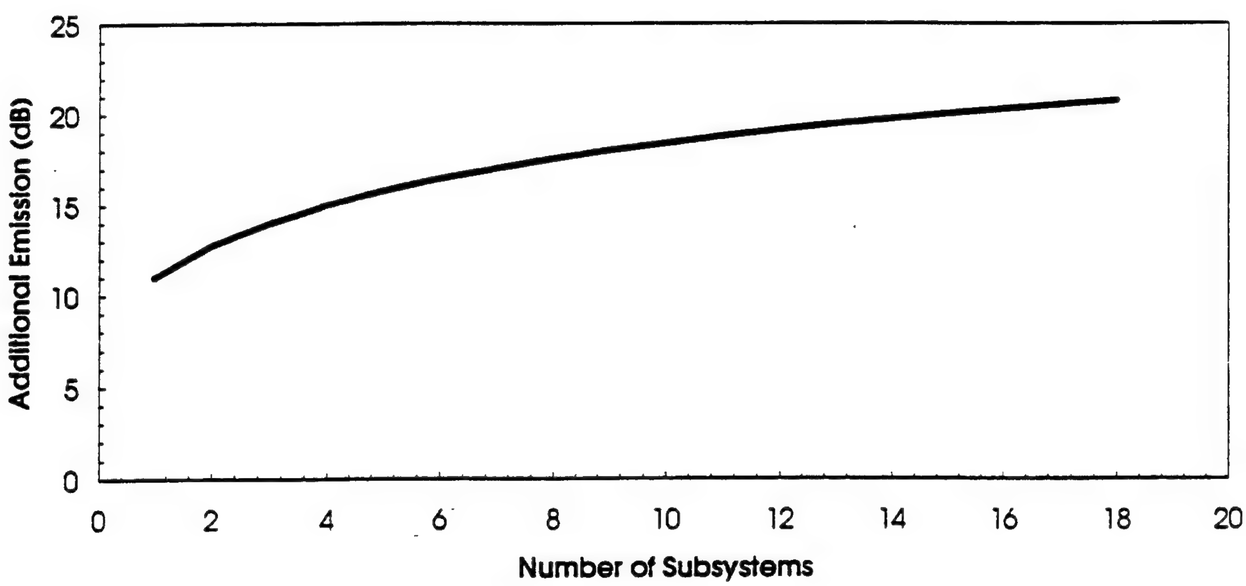

Figure 2-8. Incremental Radiated Emission from Synchronously Operating Subsystems

2.4 References for Chapter 2

2-1. American National Standard for Telecommunications, *Central Office Equipment - Electrostatic Discharge Requirements*, ANSI T1.308-1990.

2-2. International Electrotechnical Commission Standard, *Electromagnetic Compatibility for Industrial-Process Measurement and Control Equipment*, Part 2: Electrostatic Discharge Requirements, International Standard IEC 801-2, second edition, 1991.

2-3. Federal Communications Commission, Part 73 of Chapter 1 of Title 47 of the Code of Federal Regulations.

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2-7. TR-NWT-001089, *Electromagnetic Compatibility and Electrical Safety Generic Criteria for Network Telecommunications Equipment*, October 1991.

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3.0 GAMMA RADIATION

The baseline protection measures defined in this chapter for optical communication links are intended to ensure their survivability in natural and man-made gamma radiation environments of peacetime natural disasters and crisis management.

3.1 Protection Measure Recommendation

The optical fibers in fiber-optic cables intended for Public Telecommunication Networks shall be matched-clad or depressed-clad dispersion-unshifted TIA/EIA Class IVa (Reference 3-1), or dispersion-shifted EIA/TIA Class IVb (Reference 3-2) single-mode fiber. The maximum attenuation shall be 0.40 dB/km at 1.31 μm for dispersion-unshifted fiber and 0.25 dB/km at 1.55 μm for dispersion-shifted fiber. For link lengths less than 20 km, the fiber may be single-mode matched-clad or depressed-clad dispersion-unshifted TIA/EIA Class IVa (Reference 3-1), having an attenuation of less than 0.5 dB/km at 1310 nm. Class IVa single-mode fibers shall conform to the requirements in TIA/EIA-492C000 (Reference 3-1). In addition, the fiber-optic cable for outside-plant use shall conform to EIA-472D000 (Reference 3-3).

3.2 Rationale and Discussion

Fiber-optic systems have been successfully deployed for long-haul telecommunication links for over a decade. The potential of optical fibers for unlimited bandwidth capacity (compared to copper-conductor circuits) has made optical fiber the transmission medium of choice for terrestrial transmission of telephony as well as for data and video. The ten million fiber kilometers deployed in the United States have been primarily for connectivity of long-distance and interoffice networks through buried or underground installations.

Today, fiber-optic systems are transmitting at 2.5 Gb/s on conventional single-mode fibers and at 10 Gb/sec on dispersion-shifted fibers. This concentration of information on a single fiber places a requirement for high reliability. Fiber's attributes of high bandwidth capacity and the publicized immunity to electromagnetic interference have overshadowed its vulnerability to environmental degradation. A large body of research exists on the mechanical attributes of fiber strength and static fatigue and on hydrogen-induced losses, but there is a critically important knowledge gap with respect to optimizing the radiation resistance of single-mode cables that are soon to be employed in inner-city fiber transmission links (Reference 3-4).

3.2.1 Network Robustness

The baseline recommendations for fiber-optic links are based on the communications support required to accomplish the National Security/Emergency Preparedness (NSEP) mission. The construction of these links must be considered within the context of the NSEP environments for fixed outside plant.

Four environments of NSEP telecommunication are considered (Reference 3-5):

- peacetime natural disasters
- crisis management
- limited conventional war
- nuclear war.

Each of these presents special concerns to providers of NSEP communications services.

The recommended baseline measures are limited to those needed for survivability in the environments of peacetime natural disasters and crisis management. The network needs for communication in a limited conventional war and nuclear war, assuming that fixed-plant communication will be severely damaged or destroyed, are considered to be above-baseline measures. An allowable network recovery time of 10 minutes has been suggested for the network after the emergency in order to support the NSEP mission (Reference 3-5). This time requires that the system generally will automatically recover, and no human intervention (except perhaps for initiating a recovery cycle) is assumed (Reference 3-5). Crisis management situations include international incidents such as hijackings and terrorist activities, and domestic incidents such as the accident at Three Mile Island (TMI), but none of the magnitude of the Chernobyl Nuclear Reactor Station explosion or third-party military actions that may result in heightened tensions at home or abroad.

3.2.2 Sources of Gamma Radiation

Natural sources of radiation include radioactive isotopes, which occur in soils and materials in the terrestrial and undersea environments, and extraterrestrial sources such as cosmic rays, solar energy and radiation, and Van Allen Belt radiation (Reference 3-6). In the earth's upper crust, the primary natural sources of radiation — uranium (U), potassium (K), and thorium (Th) — must be considered in assessing optical-fiber degradation. It has been estimated that under normal ambient conditions, a fiber-optic cable buried at 1 meter receives 150 mrads per year. This was based on average soil concentrations of 3 ppm U, 2 percent K, and 6 ppm Th. An upper bound dose rate of 500 mrads per year was estimated for roughly 95 percent of the continental U.S. This concentration typically occurs over small areas, so it is unlikely that the entire long-haul or trunk cable would be exposed to a dose rate of 500 mrads per year. A dose rate of 150 mrads per year is representative of most of the underground environments in which fiber-optic cable is deployed (Reference 3-7). Other sources of gamma rays include operating nuclear reactors, which provide fission-product gamma rays. The average energy of fuel-element gamma rays is about 0.7 million electron-volts (Reference 3-5).

3.2.3 Exposure Levels

In keeping with the provisions of the baseline measures to ensure network survivability in peacetime natural disasters and crisis management, the limits of radiation that a fiber must

survive should be based on the federal dose limits (see Table 3-1) for occupational workers in a nuclear reactor facility.

Table 3-1. Federal Dose Limits for Occupational Workers

Dose Category	Current 10CFR20* (1/1/94)
Whole Body (WB)	5 rems per year (internal + external)
Eye	15 rems per year
Skin	50 rems per year
Extremity	50 rems per year
Organ	50 rems per year
Planned Special Exposure	1 times the annual limits per year, 8 times the annual limits per lifetime
Embryo/fetus (declared pregnant worker)	0.5 rem for the gestation period

* Title 10, *Code of Federal Regulations* (CFR), Part 20, Dose Limits.

At most, network survivability is essential in a nuclear disaster where the mortality rate is less than 100 percent as defined by an exposure range hazardous to personnel. The relationship between exposure ranges and levels of radiation sickness is shown in Table 3-2. (The data in this table are adapted from National Council on Radiological Protection and Measurements, *Radiological Factors Affecting Decision-Making in a Nuclear Attack*, Report No. 42, November 1974.)

It is common practice for a telecommunications cable to terminate at a cross-connect point immediately outside the customer facility. Therefore, the maximum radiation levels that optical cables are exposed to are typically less than those experienced by occupational workers inside the plant (Table 3-1). In a case of a localized nuclear disaster, the need for telecommunications would exist as long as personnel could staff the telecommunication system in the affected area. Considering the expected mortality of 100 percent for personnel exposed to a 600-rad dose delivered over a short period of time (see Table 3-2), it is reasonable to assume that the telecommunication system must be unaffected by this level of radiation exposure.

Table 3-2. Relationship Between Exposure and Level of Radiation Sickness

Exposure Range (rads)	Type of Injury	Probable Mortality Rate Within 6 Months of Exposure
0 - 50 R	No observable signs or symptoms	None
50 to 200 R	Level-I Sickness	Less than 5%
200 to 450 R	Level-II Sickness	Less than 50%
450 to 600 R	Level-III Sickness	More than 50%
More than 600 R	Level-IV & -V Sickness	100%

3.2.4 Radiation Susceptibility of Single-Mode Cables

The purpose of this section is not to describe in detail the effects of radiation on fibers but to summarize fiber and fabrication parameters that affect fiber performance. It is a well-known fact that glass will discolor when exposed to nuclear radiation. This irradiation causes a change in the optical properties of the glass, accompanied by an attenuation increase in the fiber-optic cable. The level of induced radiation effects on the fiber is primarily dependent on the nature and the dose rate of radiation. Other factors that must be considered are the wavelength of operation, operation temperature, and the length of the exposed fiber. Also, material composition of the optical preform and the fiber draw speed and cleanliness of the draw room affect the induced loss in the fiber after exposure to radiation.

An extensive study by E. J. Frieble (Reference 3-4) identified a recipe for preform fabrication and fiber drawing conditions to minimize the fallout radiation sensitivity of single-mode fibers operating at 1.3 µm. It was demonstrated that phosphorus (P) in the fiber will induce additional loss. However, phosphorus is one of the metal halides used in the modified chemical vapor deposition (MCVD) preform manufacturing process and is of benefit in determining fiber's recovery characteristics. Therefore, optimization of this dopant in the fiber must be achieved. Dr. Frieble and others have shown that a higher oxygen-to-reagent ratio in the core and a higher draw rate increase the radiation resistance of the fiber. Today's fibers are typically drawn at a rate of 10 meters per second or more, not because of radiation resistance considerations but to produce fibers as inexpensively as possible. Also, the P concentrations in the cladding are very low in all commercially available single-mode fibers.

When optical fibers are exposed to nuclear radiation, the radiolytic electrons and holes can form color centers if they are trapped on defects that either exist in the amorphous network of

the glass before irradiation or are created by exposure (Frieble & Grissom, 1986). These optically absorbing color centers cause radiation-induced loss in the 0.85, 1.3, and 1.5 µm operating wavelength regions. The types and concentrations of the dopants have a significant effect on the radiation sensitivity of the fiber. The state of technology for fabricating preforms has evolved to minimize preform impurities to a level where the fiber's loss is approaching the theoretical limit. From the work of Frieble and others, it can be concluded that radiation-resistant fibers with reasonably short recovery times (10 to 100 seconds) are feasible (Reference 3-5). It has been shown that the attenuation loss attributable to 1000-rad exposure can be as low as 0.6 dB per km for a radiation-hardened fiber.

The sensitivity of single-mode fibers to low-dose radiation has been determined to evaluate the impact of terrestrial radiation on long-distance networks (Reference 3-7). Table 3-3 (from Reference 3-7) shows estimates for cable spans, assuming that the entire fiber length would be exposed to the radiation dose of 150 millirads per year.

Table 3-3. Radiation-Induced Loss Estimates for 20-Year Exposure to an Average Terrestrial Environment (150 mrad/year)

Operating Wavelength	Span Length (km)	20-Yr Added Span Loss on Single-Mode (dB)
1.3 µm	30-40	0.04-0.05
1.5 µm	30-40	0.06-0.08
1.3 µm	20-50	0.03-0.07
1.5 µm	20-50	0.03-0.08

3.2.5 Fiber-Optic Links

The baseline requirements for system performance must be considered within the context of NSEP environments for fixed plant telecommunication links. The telecommunication system survivability in the environments of peacetime natural disasters and crisis management becomes the baseline for system performance. Since fiber degradation caused by gamma radiation is cumulative, all possible degradation sources must be examined. The first consideration is the degradation of the system from terrestrial radiation. The estimated loss of 0.08 dB for a 50-km fiber span was predicated on exposure of the entire span to a radiation level of 150 millirads per year. It is unlikely that a significant portion would be exposed to these levels of radiation. Therefore, because an additional attenuation of 0.08 dB in the span length is insignificant in a telecommunication link, it was concluded that the excess loss caused by terrestrial radiation is negligible.

Fiber-optic links deployed in areas of nuclear reactors are typically installed by conventional methods without any additional protection. Radioactive contamination from a nuclear reactor for an accident on the order of the Three Mile Island (TMI) is not quantified in unclassified literature. Therefore, based on a crisis management condition that communication is necessary as long as the exposure level of the radiation does not exceed 600 rad, a level that is lethal to 100 percent of the exposed population, assumptions about the survivability of the link can be calculated. Corning Incorporated advertised the fiber radiation performance of their SMF-21 fiber in their 1990 product literature brochure. The data indicate that at room temperature a maximum attenuation increase of 6 dB/km was measured after an exposure to 3700 rads. After a recovery period of 10^3 seconds, the fiber loss decayed to about 1.5 dB/km. Based on the initial assumption that a system recovering within approximately 10 minutes can be classified by NSEP definition as a fully functional system for baseline measures, the 1.5 dB per km value was used to determine the possible fiber loss in the system. It has been shown that fiber loss data can be extrapolated to other exposure levels. Therefore, a 600-rad irradiation of the SMF-21 fiber should increase the attenuation of the fiber span at a rate of 0.25 dB per km. Assuming that a full kilometer length would be exposed to this level of radiation, which is not likely to happen in the case of a nuclear reactor malfunction such as the TMI failure, the additional attenuation would be 0.25 dB. The typical power budget for a link includes about 3 dB for component degradation. Based on the typically deployed transmission link, the added induced loss caused by a catastrophic disaster would be well within the power budget, and should not be a considered as an additional degradation factor for the fiber-optic system.

The foregoing assumptions may not always be applicable, and additional testing at low dose rates is essential. Actual measurements of system performance on commercially available fibers is meager, and system testing is needed to ensure the reliability of today's installed networks.

3.2.6 Immunity to Radiation

The previous sections have indicated that the quality of today's fiber cables, predominantly used commercially, is sufficient to ensure a baseline level of immunity to gamma radiation. This immunity results from the minimization of defects and impurities by means of modern fabrication techniques that achieve attenuation losses approaching theoretical limits. The protection measure of Section 3.1 seeks to ensure that cables having low attenuation continue to be used as telecommunication links and that they are based on a nationally recognized EIA/TIA standard. The essential factor is to ensure that cables of the quality used in most installations today continue to be installed. Fiber attenuation is the best indicator of impurities and defects within the core. Today's low-attenuation fibers minimize sensitivity to radiation. The cited TIA/EIA specifications for optical fibers control the attenuation at sufficient levels and well within the manufacturing capabilities.

3.3 References for Chapter 3

3-1. TIA/EIA-492C000, *Sectional Specification for Class IVa Dispersion-Unshifted Single-Mode Optical Fibers.*

3-2. TIA/EIA-492D000, *Sectional Specification for Class IVb Dispersion-Shifted Single-Mode Optical Fibers.*

3-3. TIA/EIA-472D000, *Sectional Specification for Optic Communication Cables for Outside Plant Use.*

3-4. E. J. Friebele, *Correlation of Single Mode Fiber Fabrication Factors and Radiation Response*, NCS Technical Information Bulletin 91-11.

3-5. J. A. Hull, *NSEP Fiber Optics Systems Study, Background Report: Nuclear Effects on Fiber Optic Transmission Systems*, NCS Technical Information Bulletin 87-26.

3-6. S. R. Nagel, *Optical Fiber Telecommunications II*, edited by S. E. Miller and I. P. Kaminow (Academic Press, Inc., San Diego, CA).

3-7. J. B. Haber, E. Mies, J. R. Simpson, S. Wong, "Assessment of Radiation-Induced Loss for AT&T Fiber-Optic Transmission Systems in the Terrestrial Environments," *Journal of Lightwave Technology*, Vol 6, No. 2, February 1988, Pg. 150-154.

4.0 SOLAR RADIATION FROM MAGNETIC STORMS

This chapter presents basic measures for foundation-level protection of telecommunication links from normally encountered stresses resulting from earth currents caused by solar magnetic storms.

4.1 Protection Measure Recommendations

4.1.1 Battery Reserve Time and Standby Engine-Alternators

Battery reserve time and standby engine-alternators for the power plants of telecommunication links shall satisfy the requirements of Sections 11.1.2 and 11.1.4 of *Protection of Telecommunication Links from Physical Stress* (Reference 4-1).

4.1.2 DC Potential Difference

Telecommunication links serving terminal equipment that has a conductive connection to earth shall operate properly in the presence of a dc potential of ±3 volts between the ends of the link.

4.1.3 Surge Protectors

Surge protectors for copper-conductor links at telecommunication centers, in locations where the earthing networks at terminations of the links are not interconnected by continuous power-line neutrals or cable shields, shall satisfy the Induced Low Current test of standard UL497 (Reference 4-2).

4.2 Rationale and Discussion

An indirect threat to telecommunication links is the possible loss of power supplied by the local power utility during a severe magnetic storm. Such a power outage can affect continuity of telecommunication service, and is addressed in Section 4.2.1.

The nature of the solar-magnetic phenomenon makes it apparent that any direct threat would occur only on long links. However, most of the long wire-line telecommunication links being installed in the interexchange plant are optical links, so dc potential differences in the earth do not pose a direct threat to them. Links in the exchange plant average 4 km, too short to be disturbed by magnetic storms; only the longest links at 15 to 30 km are of direct concern. They and the power supplies for optical-fiber or copper-conductor links, which may have widely spaced connections to earth, should be able to function under normally encountered conditions. This is covered in Section 4.2.2.

Extreme conditions during unusually severe magnetic storms may occasionally cause surge protectors to operate. Such an occurrence is so rare that service interruptions are tolerable, but measures should be taken to avoid the possibility of a fire (Section 4.2.3).

4.2.1 Backup Power

Power utilities have experienced widespread outages during magnetic storms. Most recently, in 1989, the Province of Quebec was blacked out and a large transformer was permanently damaged in New Jersey (Reference 4-3). This disruption of power grids is largely caused by saturation effects in power transformers and related components. The duration of such a blackout can be long; in Quebec, 9 hours after the initial event, 17 percent of the load was still out of service (Reference 4-4).

This possible loss of utility power is probably the greatest threat posed to telecommunication links by magnetic storms. Public telecommunication networks use power from the utilities for operating the links and the terminating equipment. Continuity of power to the networks during periods of power utility blackout can be maintained by a system of reserve batteries in conjunction with engine-alternators. During an extended power outage, the batteries can supply power for several hours and may be backed up by the engine-alternators. Such a system provides uninterrupted power to the telecommunication network for the duration of the power outage.

Because there are many causes of power utility outages, telecommunication companies routinely install appropriate reserve power systems. A system that has proven to be satisfactory is described in Reference 4-1. Such a system is unlikely to be directly affected by a magnetic storm, and it is capable of providing satisfactory reserve power if a power utility experiences an extended outage.

Since many power utilities use public telecommunication networks for their protective relaying and supervisory circuits, an important aspect of providing reserve power systems in public telecommunication networks is that doing so keeps the networks available to assist in restoration of the power utility.

4.2.2 DC Potential Difference

As described in Section 1.8, only circuits that have a resistive connection to earth are affected by geomagnetic potential differences under normal circumstances (no operation of surge protectors). This is because the earth currents do not produce any induced-voltage effects at the near-dc frequencies involved, so a resistive path to earth would be needed for currents to reach the conductors of a wire-line telecommunication link.

In an effort to characterize the magnitude of dc voltage that may exist between the ends of a link, measurements were made on local lines and were summarized in an unpublished report of the predivestiture Bell System. The dc potential difference between the ground terminal of

the station protector and the earthing network at the central office was measured on 409 randomly selected local lines. Eighty-seven percent of the lines had less than a 0.25-volt difference, indicating the strong possibility of a metallic connection between the two ends of the links. Such a connection could have been provided by the neutral conductor of the power utility or by a metallic shield of the telecommunication cable. The sample had 0.5 percent of the readings between 1.5 and 2.5 volts, with no reading above 2.5 volts.

This survey was done in 1980, during the 21st sunspot cycle. The geomagnetic activity associated with the 21st cycle began in 1977 and peaked in 1982 (Reference 4-5). Therefore, the measured voltages characterize a period of high, but not extreme, geomagnetic activity.

The capability of providing service at earth potential differences as high as 3 volts dc encompasses, with some margin, the values measured in the survey. It is a performance goal that has been used successfully for some time in the setting of requirements on telephone equipment (Reference 4-6). This level of immunity not only provides a reasonable level of protection from magnetic storms, but also provides a measure of protection against other sources of dc earth potential differences, such as dc power transmission systems, traction lines, and cathodic protection rectifiers.

4.2.3 Surge Protectors

Surge protectors are placed at central-office terminations of wire-line telecommunication links to limit the energy from surges that would otherwise damage terminal equipment. A brief surge, such as one caused by nearby lightning, causes the protector to momentarily enter its conducting mode, limiting the magnitude of the surge, after which it returns to its nonconducting quiescent state. However, a sustained overvoltage, if it is initially high enough to operate the protector (i.e., above its dc limiting voltage), can subsequently decrease in magnitude and still keep the protector in conduction. If such a surge continues for more than a few seconds, enough power can be dissipated by the protector to cause it to overheat.

The power generated by a surge protector while it is limiting a surge is the product of the portion of the surge current it conducts and the conducting voltage of its corresponding operating mode. Higher currents generally produce a lower conducting voltage. For instance, the conducting voltage of a typical gap-type protector in its arc mode at 2 amperes is 20 to 30 volts. At lower currents, the protector in its glow mode may have a conducting voltage of 125 volts (Reference 4-7). Accordingly, a sustained 2-ampere current can generate about 50 watts, while 0.5 amperes generates more than 60 watts. These power levels can overheat protectors and nearby apparatus. Such overheating has occurred during severe magnetic storms, causing fire damage in several telecommunication centers (Reference 4-8).

Damage caused by overheating of protectors can be avoided by incorporating in them a heat-detecting mechanism that automatically grounds the line before overheating occurs. This is routinely done on protectors located at the customer's end of a link, as is required by the listing provisions of the National Electrical Code (Reference 4-9). However, listing of

protectors is not required at the central-office termination of the link, so it would be prudent to otherwise ensure their ability to conduct the currents generated by a magnetic storm.

The amplitude of currents driven by geomagnetic potentials is likely to be small. It is limited by the resistance of the conductor and the earthing network. On a long exchange-cable link, this resistance is likely to exceed 600 ohms. A potential difference between ends of the link would have to exceed about 250 volts to operate a protector; about 400 volts would be needed to operate two protectors. Such events could then cause currents ranging from 0.5 to 1.0 amperes.

The current used in the Induced Low Current Test of Standard UL497 is from 0.25 through 2.0 amperes, and covers the expected range of currents caused by magnetic storms. In order to pass the test, the protector must not pose a fire hazard while conducting the current, and it must continue to limit voltages afterward. Therefore, ability to pass the test would help to ensure the desired capability in the protectors. In areas where the earthing networks at the ends of links are conductively interconnected, voltages that are high enough to operate protectors do not occur, and such a capability is unnecessary.

In view of the possible serious consequences of fire in a telecommunication center (Reference 4-10), the ability of protectors to safely conduct the currents caused by magnetic storms is important. Although the possibility for operation of protectors is small, the measure should not prove costly. Furthermore, there is an increasing tendency to use listed protectors even where not required by codes, and this new capability is in line with that trend. As a result of exempting links with interconnected earthing networks at their terminations, most large population centers are not affected.

4.3 References for Chapter 4

4-1. *Protection of Telecommunication Links from Physical Stress*, Technical Information Bulletin 33-9, National Communications System, June 1993.

4-2. *Protectors for Paired Conductor Communication Circuits*, UL497, Underwriters Laboratories, 1991.

4-3. V. Albertson, J. Kappenman, "Cycle 22: Geomagnetic Storm Threats to Power Systems Continue," *IEEE Power Engineering Review*, September 1991.

4-4. V. Albertson, J. Kappenman, "Bracing for the Geomagnetic Storms," *IEEE Spectrum*, March 1990.

4-5. M. Gao, "A Comparison of Solar and Geomagnetic Activities from the 13th to the 21st Solar Cycles", *Solar Wind-Magnetosphere Coupling*, (Terra Scientific Publishing Co., Tokyo), 1986, Pages 149-160.

4-6. *Electromagnetic Compatibility and Electrical Safety Generic Criteria for Network Telecommunication Equipment*, Issue 1, Bellcore Technical Reference, TR-NWT-001089, October 1991.

4-7. *IEEE Guide for the Application of Gas Tube Arrester Low-Voltage Surge Protective Devices*, ANSI/IEEE Standard C62.42-1987.

4-8. G. Swedenborg, K. Wyke, "Disturbances Caused by Earth Currents to Telecommunication Plants," *TELE*, No. 1, Stockholm, 1959, Pages 41-48.

4-9. 1993 National Electrical Code, ANSI/NFPA 70-1993.

4-10. J. B. Eibel, "Fire Prevention in Telecommunications Facilities," *Network Reliability*, Section G, National Engineering Consortium, June 1993.

5.0 CONCLUSIONS

Measures have been described that are intended to provide a baseline level of protection for links of telecommunication networks against certain radiation effects. The proposed measures are intended to establish foundation-level protection from damage caused by these radiation effects under typical geographic and local environmental conditions.

The radiation effects that have been considered are:

- electromagnetic interference

- gamma radiation

- solar magnetic storms

This report on radiation effects augments the report, *Protection of Telecommunication Links from Physical Stress*, NCS TIB 93-9. These two reports provide technical background and protection measures that address all aspects of the Standards Project Proposal (T1 LB 273, revised 1/16/92) covering the standard, *Protection of Telecommunication Links from Physical Stress and Radiation Effects (a Baseline Standard).*

The proposed protection measures are summarized in the following paragraphs, by category according to the radiation effect that is addressed.

5.1 Electromagnetic Interference

The protection measures address electromagnetic interference by specifying that electronic equipment in telecommunication links have a baseline level of immunity to electromagnetic fields. The measures cover immunity from continuous and broadband sources. Continuous sources include high-power radio transmitters, portable transmitters, and nearby electronic equipment. Examples of broadband sources are electric motors, combustion engines, and electrostatic discharges.

The measures set a level of immunity to narrowband *electric* fields over the frequency range 10 kHz to 10 GHz. Immunity to narrowband *magnetic* fields is specified over the frequency range 60 Hz to 30 kHz. A measure of immunity to broadband sources is provided by requiring electronic equipment to be immune to indirect electromagnetic discharges applied in accordance with national and international standards.

5.2 Gamma Radiation

Gamma radiation can cause increased attenuation in optical fibers. This attenuation effect can be made acceptable at baseline threat levels by minimizing the impurities and imperfections in

the fibers. The protection measure requires the use of fibers that have sufficiently low attenuation, and is based on EIA/TIA standards that cover optical fibers.

5.3 Solar Magnetic Storms

Solar magnetic storms occur with varying degrees of intensity about every 11 years, causing low-frequency voltage differences in the earth. These storms have caused widespread outages on ac power systems that power telecommunication links, and the possibility of recurrence is probably the most critical threat to continuity of communications. The corresponding protection measure reinforces the need for sufficient battery reserve time and standby engine-alternators for telecommunication links.

Continuity of service is further addressed by a measure requiring links that have a conductive connection to earth to operate properly in the presence of ±3 volts between the ends of the link.

A final measure addresses the possibility of overheating surge protectors on the links at the telecommunication center. This possibility is dealt with by requiring that such surge protectors safely conduct low levels of current for the duration of the solar event.